Handbook of Operating Instructions for

AIL Type 30

Precision I-F Attenuator

August 1960

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Airborne Instruments Laboratory

A DIVISION OF CUTLER-HAMMER, INC.

Deer Park, Long Island, New York

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OPERATING INSTRUCTIONS FOR
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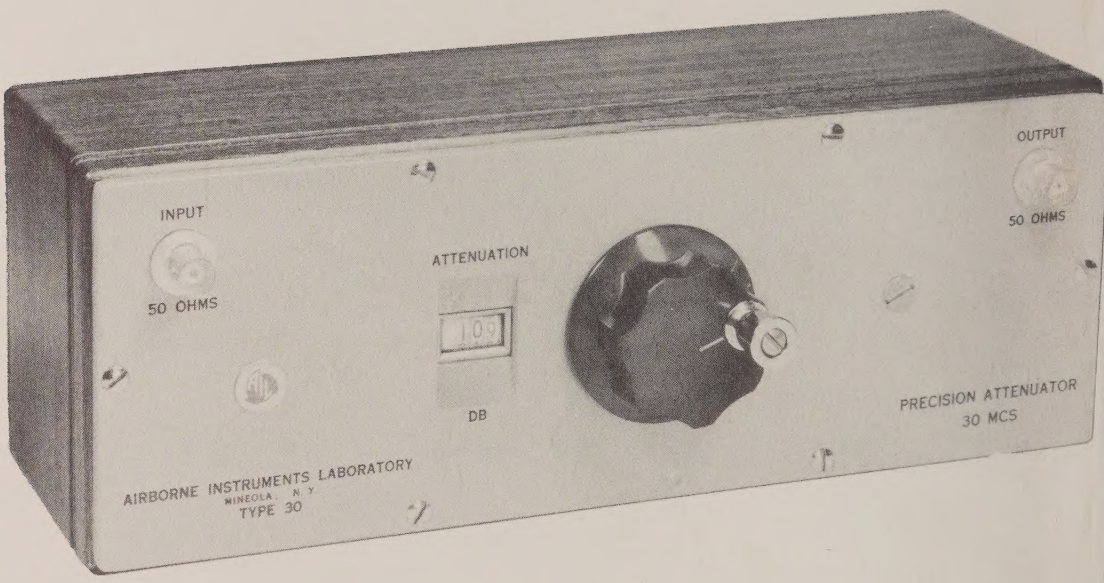
TABLE OF CONTENTS

		Page
I.	Introduction	1
II.	Theory of Operation	2
	A. Incremental Attenuation	2
	B. Minimum Insertion Loss	4
	C. Impedance Characteristics	5
III.	Precautions and Limitations on Use	7
	A. Frequency Limitations	7
	B. Maximum Permissible Input Power	7
	C. Limitation on Shaft Speed	8
	D. Torque and Backlash	8
	E. Accuracy	8
	F. Bandwidth	8
IV.	Applications	9
V.	Type 30 at Other Frequencies	9
VI.	Physical Features	10
VII.	Lubrication	10

LIST OF ILLUSTRATIONS

Figure	
Frontis-piece	AIL Type 30 Precision I-F Attenuator
1	Equivalent Circuits for AIL Type 30 Precision I-F Attenuator
2	Average Resistance vs Frequency Curves
3	Average Reactance vs Frequency Curves
4	Minimum Insertion Loss vs Frequency Curve
5	Outline and Mounting Dimensions for AIL Type 30 Precision I-F Attenuator



AIL TYPE 30 I-F PRECISION ATTENUATOR

I. INTRODUCTION

The AIL Type 30 Precision I-F Attenuator is a device designed for use at about 30 Mc. It provides precise and continuously variable attenuation above its minimum insertion loss of about 22 db between 50-ohm resistive loads. It is valuable for use as a laboratory attenuation standard.

The attenuator is basically a circular waveguide operating well below cutoff. This permits the attenuation, in db, between input and output of the waveguide to be an accurate linear function of the separation of input and output circuits. A lead screw controlling this spacing is geared to a counter, which is calibrated in db of loss above that at minimum spacing (the loss at minimum spacing between 50-ohm resistive loads being called the minimum insertion loss). The incremental attenuation is continuously variable from 0 to about 80 db. It is accurate to 0.005 db per db of indicated scale reading and is independent of frequency in the approximate range of 10 to 225 Mc.

Inductive coupling is used at both the input and output of the waveguide. Each inductor is in series with an appropriate capacitor and resistor. Since the input and output impedances at 30 Mc are primarily resistive, the Q of the circuits is very low.

The minimum insertion loss varies with frequency within the 10 to 225 Mc range. This means that the absolute attenuation for a given dial setting varies with frequency. The counter always reads decibels of attenuation above the minimum insertion loss.

Movement of the input coil is effected by a spring-loaded bevel gear and a lead screw. Another bevel gear is mounted on the drive shaft. This gear meshes with the bevel

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gear that is threaded to the lead screw. The input coil assembly is attached to the end of the lead screw. As the bevel gears turn, the lead screw, which cannot rotate because of a restraining stud, must advance or recede, depending upon the direction of rotation of the drive shaft. This changes the distance between the input coil and the output coil, which is fixed-mounted at the end of the waveguide, thereby varying the attenuation.

A spur gear is coupled to the lead screw and bevel-gear assembly, thus forming an antibacklash gear. The counter gear of the Veeder-Root counter is also coupled to the spur gear. The tolerances associated with the lead screw and gear assembly, together with the tolerance on the waveguide diameter, limit the error in scale reading to a maximum of 0.005 db per db of indicated scale reading.

II. THEORY OF OPERATION

A. INCREMENTAL ATTENUATION

The incremental attenuation in the Type 30 is provided by varying the distance between coplanar radiating and pickup coils in a circular waveguide below cutoff. The lowest mode that will be propagated in a circular waveguide is the $TE_{1,1}$ mode. For this mode, the cutoff wavelength is equal to 1.71d, where d is the internal diameter of the waveguide. In the Type 30, d is 1.27 cm. This gives a value of λ_c of 2.17 cm, which corresponds to a frequency of 13,800 Mc. Since the attenuator is intended for use much below this frequency, it is always operating well below cutoff.

There is no true wave propagation in a waveguide below cutoff. The fields are exponentially attenuated down the length of the waveguide with the value of attenuation

constant depending upon the mode. For any single mode, therefore, the attenuation in decibels is a linear function of the length of the waveguide. The effective length of the waveguide is changed by varying the separation of the coils. Since for any one mode the attenuation in decibels is a linear function of the separation between coils, the linear Veeder-Root counter will indicate directly in decibels.

In addition to being the lowest mode that will propagate in a circular waveguide, the $TE_{1,1}$ mode also has the lowest attenuation constant below cutoff. For this reason the $TE_{1,1}$ mode is used in the Type 30.

The attenuation constant α for the $TE_{1,1}$ mode is

$$\alpha(\text{db/cm}) = \frac{32.0}{d}\sqrt{1 - \left(\frac{1.71d}{\lambda}\right)^2} \qquad (1)$$

where

λ = free-space wavelength in cm
d = diameter of guide in cm

For a frequency of 30 Mc, this becomes

$$(\text{db/cm}) = \frac{32.0}{1.27}\sqrt{1 - \left(\frac{1.71 \times 1.27}{1000}\right)^2} \qquad (1A)$$

Since the squared term is very small with respect to unity, we see further that the attenuation constant is essentially independent of the wavelength at the longer wavelengths and therefore independent of frequency up to about 225 Mc. Impedance characteristics, however, may limit the use of the Type 30 before this frequency is reached (equations 4 and 4A).

B. MINIMUM INSERTION LOSS

Near the radiating coil, modes other than the $TE_{1,1}$ are of comparable strength. If the pickup coil were sufficiently close to the radiator to pick up these other modes, the attenuation in decibels would not vary linearly with separation because of the different attenuation constants for the various modes. To avoid this nonlinearity, there is a minimum separation that is maintained between the two coils. Since the attenuation constants for the other modes are greater than for the $TE_{1,1}$ mode, this ensures that the other modes are attenuated sufficiently below the $TE_{1,1}$ mode to be negligible at the pickup coil. However, this separation also causes a relatively large insertion loss even with the coils in the position of minimum attenuation.

Figure 1A is a simplified version of the piston-attenuator circuit. Neglecting all stray circuit elements, the Type 30 can be represented by two loosely coupled series-resonant circuits (Figure 1A). This is a reasonably correct representation of the Type 30 for frequencies up to about 20 Mc. Figure 1B is a more accurate equivalent circuit for the Type 30, taking the major stray circuit elements into account. This is a valid representation of the Type 30 for frequencies up to 100 Mc. For frequencies above 100 Mc, an even more sophisticated equivalent circuit will be required. For most applications, however, the circuit shown in Figure 1B will suffice.

The large minimum insertion loss of the attenuator means that the coefficient of coupling, k, is always very much less than unity and the essential independence of frequency of the attenuation constant, α, ensures that k is independent of frequency below 225 Mc. Under these conditions, the simple circuit shown in Figure 1A gives rise to the transfer function, H:

$$H = \frac{j\,\omega M R_L}{Z_{11}Z_{22} + \omega^2 M} \qquad (2)$$

where

M = mutual inductance

$$Z_{11} = R_1 + j\left(\omega L_1 - \frac{1}{\omega C_1}\right)$$

$$Z_{22} = R_2 + j\left(\omega L_2 - \frac{1}{\omega C_2}\right)$$

The more nearly correct circuit shown in Figure 1B gives rise to a very complicated transfer function. The value of $|H|$ for this more complicated transfer function is, however, not greatly different from that of $|H|$ given in equation 2 if the capacitances are not too large. The effect of the additional stray circuit elements in Figure 1B appears mainly in the phase angle of $|H|$. Thus, it is not surprising that the experimentally measured characteristic of $|H|$ as a function of frequency, which is given in Figure 4, does not depart drastically from the value of $|H|$ given by equation 2. (The curve shown in Figure 4 was taken with the attenuator operating between 50-ohm loads.)

C. IMPEDANCE CHARACTERISTICS

As expected, the resistive and reactive components of the input and output impedances of the Type 30 are much more sensitive to the presence of the stray circuit elements than is the magnitude of the transfer function, $|H|$. The simple circuit shown in Figure 1A predicts a frequency dependency of the input (or output) resistive and reactive components of the form

$$X = \frac{\omega^2 a + b}{\omega C}$$

$$R = \text{constant} \qquad (3)$$

where

a and b = circuit constants

whereas the more nearly correct circuit shown in Figure 1B predicts

$$R = \frac{d\omega^4 + e\omega^2 + f}{\omega^6 + g\omega^4 + h\omega^2 + \ell} \qquad (4)$$

$$X = \frac{m\omega^6 + n\omega^4 + p\omega^2 + q}{\omega(\omega^6 + s\omega^4 + t\omega^2 + u)} \qquad (4A)$$

where

d, e, f, ... = circuit constants.

(In equations 3, 4, and 4A, we assume that k = 0.) The experimentally measured curves of resistive and reactive components of the input and output impedances as a function of frequency are shown in Figures 2 and 3, respectively. Although these curves are in good agreement with those predicted by equations 4 and 4A, they are drastically different from the curves predicted by equation 3.

It can be seen from the curves (Figure 3) that at the design center frequency of 30 Mc, the reactive components are small but are varying rapidly with frequency. The frequency at which zero reactance occurs varies slightly between different attenuators. In the case of the input impedance, the first crossing of the axis by the reactance curve is due to series resonance of the equivalent inductive reactance due

to C_1'' and L_1 with the capacitive reactance of C_1. (C_1' may be neglected at about 30 Mc.) The second crossing is due to parallel resonance of the inductive reactance due to C_1'', L_1, and C_1 with the capacitive reactance of C_1'. This is verified by the typical parallel resonant peak in the resistive component curve (Figure 2).

At still higher frequencies, the stray shunting capacitance C_1' determines the reactance characteristic (Figure 3). The output impedance components behave in a similar manner.

III. PRECAUTIONS AND LIMITATIONS ON USE

Several factors limit the specialized applications of the Type 30. These are restrictions that may be important in unusual cases but which should not hinder greatly the general use of the device.

A. FREQUENCY LIMITATIONS

The low impedance at high frequencies due to shunting stray capacitances C_1' and C_2' may impair the usefulness in this range (above 225 Mc). In the neighborhood of 225 Mc, the incremental attenuation begins to be frequency-dependent. Above 225 Mc, the error in incremental attenuation will start to become appreciable and will increase with a rise in frequency.

As a result of the 18-db-per-octave increase in minimum insertion loss below 20 Mc, the minimum insertion loss will usually be prohibitive at frequencies below about 10 Mc.

B. MAXIMUM PERMISSIBLE INPUT POWER

Since there is a 1-watt resistor in the input circuit of the attenuator, the input power should be restricted

to 1 watt maximum. The power output is similarly limited to 1/2 watt; however, because of the large attenuation in the device, this is not likely to be exceeded if the input power is below 1 watt.

C. LIMITATION ON SHAFT SPEED

To obtain the extreme accuracy of this device, a precise system of gearing is used. This gear train cannot be driven at high speed because of its close tolerances. In any installation where the attenuation is varied by a motor, the speed must be geared down to prevent exceeding the speed of normal manual operation. Precaution should be taken that torque is removed from the shaft when the coil has reached its maximum or minimum displacement.

D. TORQUE AND BACKLASH

The torque that must be applied to turn the shaft is from 7 to 20 in. oz. There is negligible backlash, however, because of the close tolerances of the gear train. No adjustment can be made to change torque or backlash.

E. ACCURACY

The incremental attenuation is accurate to within 0.005 db per db of indicated scale reading. The error in reading is due to an accumulation of tolerances on the waveguide diameter, the lead-screw variations, the gear train, and the Veeder-Root counter, and includes the small frequency error. To minimize the effects of backlash, readings of the counter dial should be approached from one direction, because the error introduced by backlash in two directions would be additive.

F. BANDWIDTH

The lowest minimum insertion loss occurs near 35 Mc and the attenuator has a bandwidth of about 20 Mc about this

point. The band pass is unsymmetrical. Figure 4 shows the minimum insertion loss as a function of frequency. This minimum insertion loss may be prohibitive at very high or very low frequencies. This band-pass characteristic must be taken into account for broad-band or pulse applications.

IV. APPLICATIONS

As a result of its extreme accuracy, the Type 30 will be found to be extremely useful as a laboratory attenuation standard. As such, the Type 30 is uniquely adapted to precision attenuation measurements. Some typical applications are:

1. I-F noise-figure measurement
2. I-F calibration of attenuators
3. Measurement of i-f amplifier gain
4. I-F subclutter visibility measurements
5. Ultrasonic line-attenuation measurements

V. TYPE 30 AT OTHER FREQUENCIES

The Type 30 is available at other than 30-Mc center frequencies. Although the theory of operation is similar to that of the 30-Mc unit, the circuit parameters are changed for the new center frequency. The shapes of the various curves are similar to those of the 30-Mc unit; however, the curves will be translated on the frequency axis to reflect the change of the center frequency.

VI. PHYSICAL FEATURES

Dimensions:

Mounted: 11 inches long by 4 inches wide by 3-3/4 inches high

Unmounted: See Figure 5

Weight:

Mounted: 3-1/4 pounds

Unmounted: 1-1/4 pounds

The case is made of walnut with an aluminum panel.

VII. LUBRICATION

A drop of light instrument oil should be added every six months to the bearings and the piston (see Figure 5). Crank the piston about 1/2 inch out from the fully seated position and add the oil. To distribute the oil, turn the drive shaft so that the piston is moved in and out. To lubricate the bearings, hold the attenuator so that the oil runs in toward the bearing.

CAUTION

Do not overoil, because oil inside the piston and the sleeve can cause electrical malfunction.

RETURN OF EQUIPMENT TO FACTORY FOR REPAIRS

If it has been found necessary to return the equipment to the manufacturer for repairs, please write first to the AIL Sales Department, giving complete information concerning the nature of the failure and the manner in which the equipment was used when failure occurred. Also provide the TYPE AND SERIAL NUMBERS of the unit. Special instructions will then be supplied to the customer for shipping the unit back for repairs. All equipment should be packed and shipped, in accordance with these instructions, with transportation charges prepaid. A failure report should accompany shipment of the equipment. Sufficient packaging material should be used so that in-transit damage is avoided.

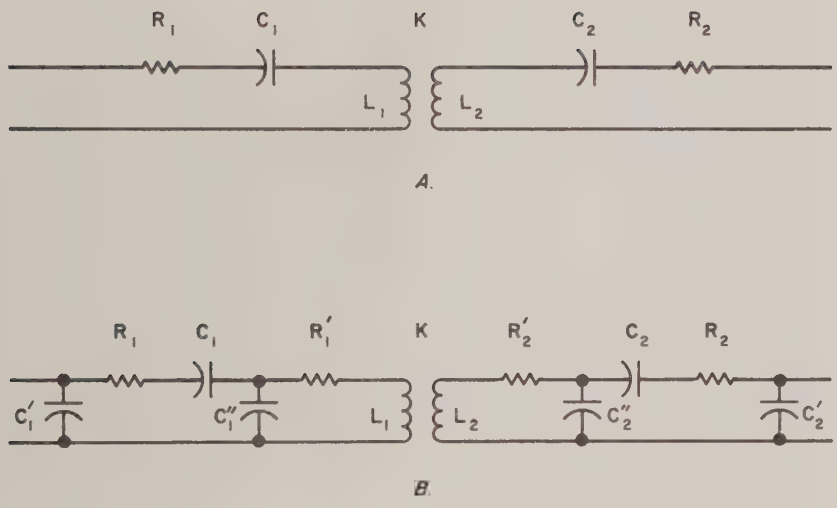

FIGURE I. EQUIVALENT CIRCUITS FOR AIL TYPE 30 PRECISION ATTENUATOR

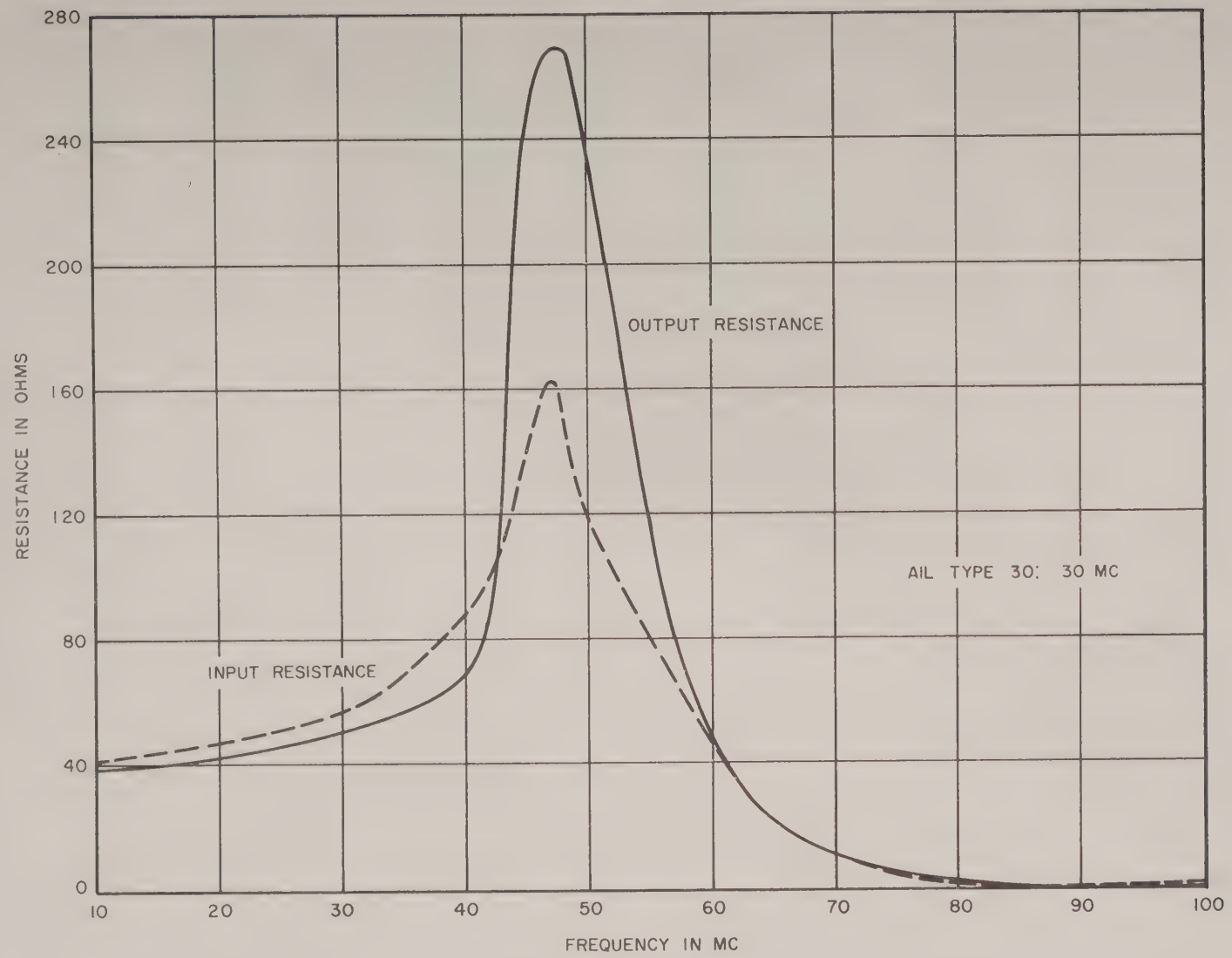

FIGURE 2. AVERAGE RESISTANCE VS FREQUENCY CURVES

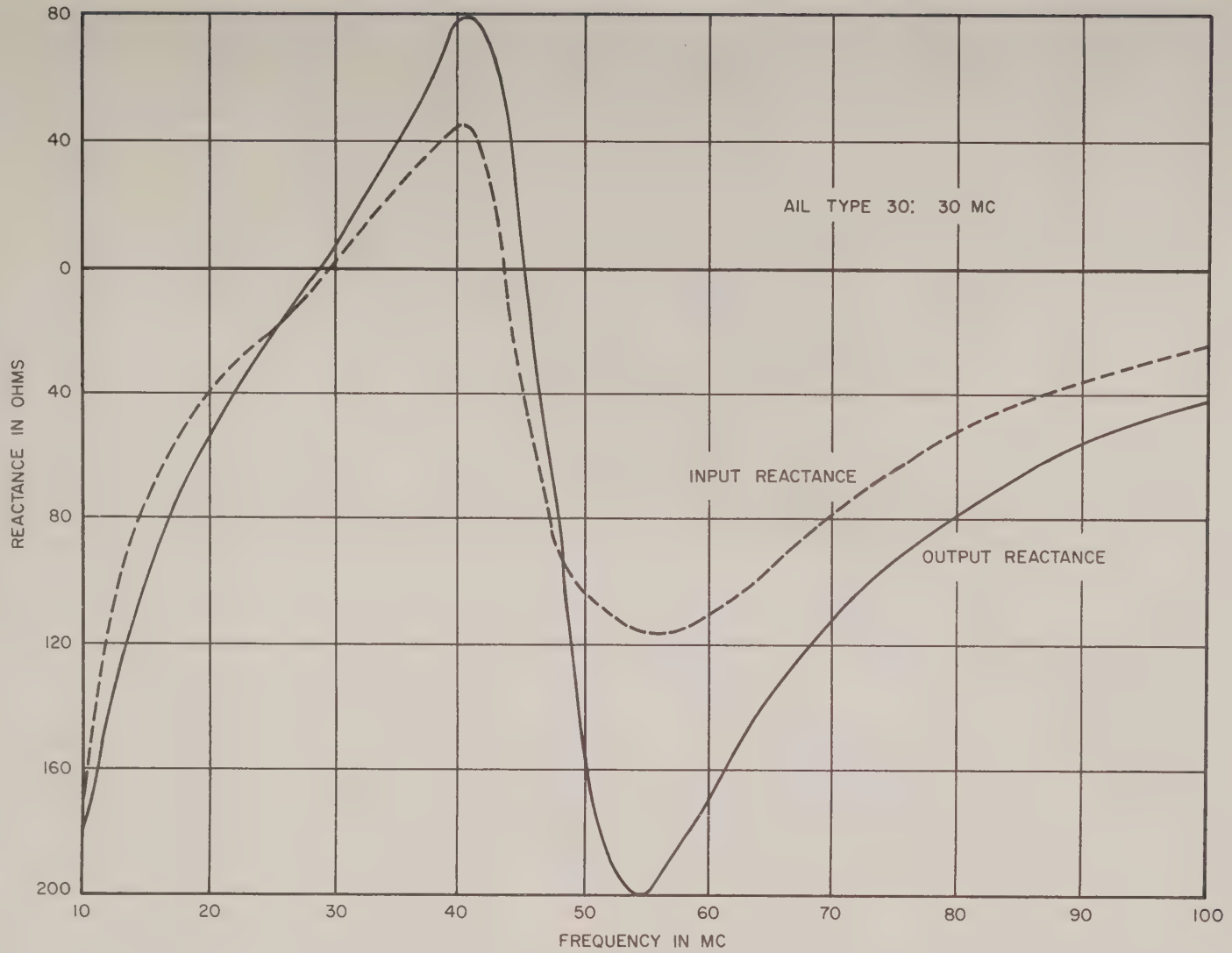

FIGURE 3. AVERAGE REACTANCE VS FREQUENCY CURVES

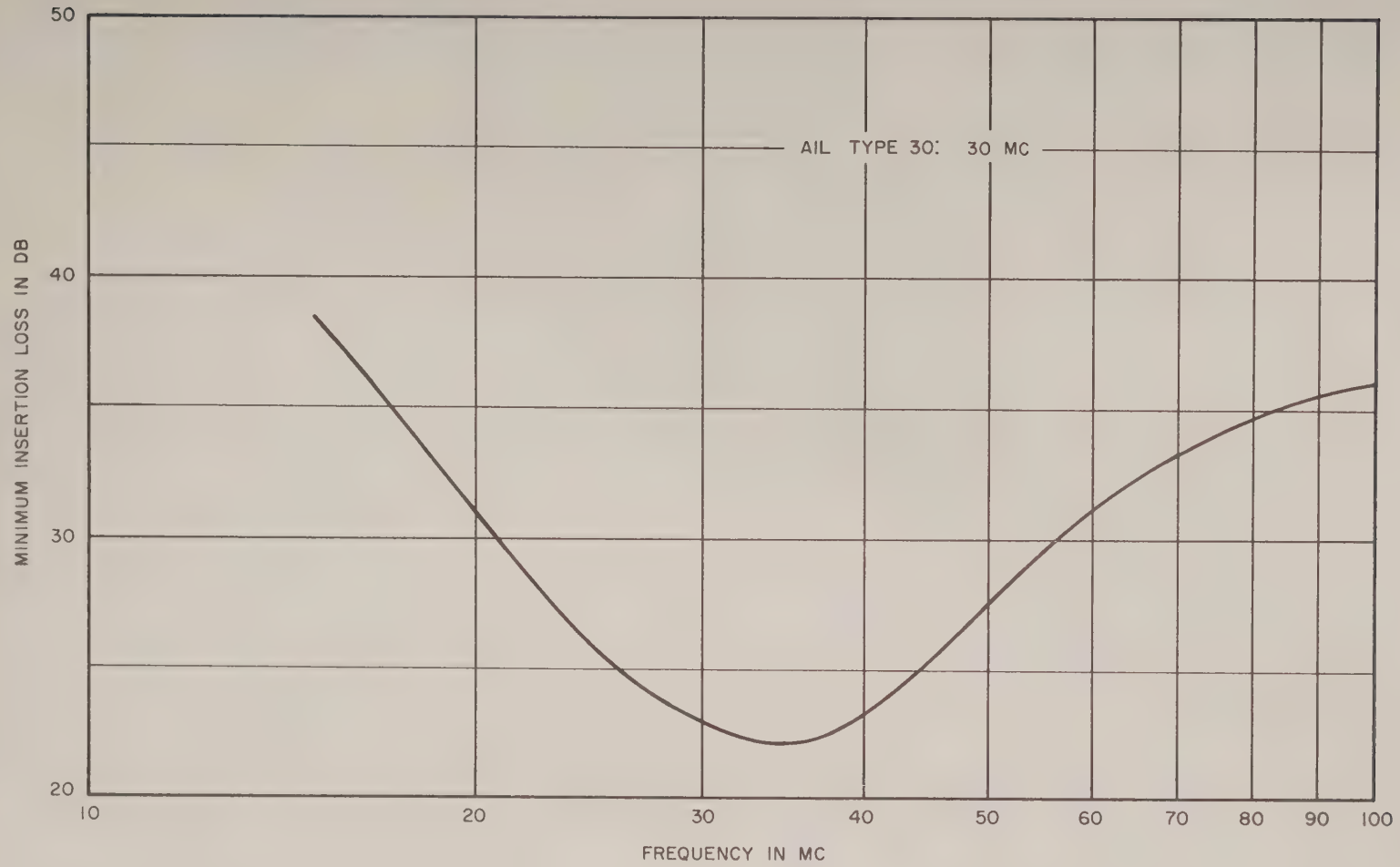

FIGURE 4. MINIMUM INSERTION LOSS VS FREQUENCY CURVE

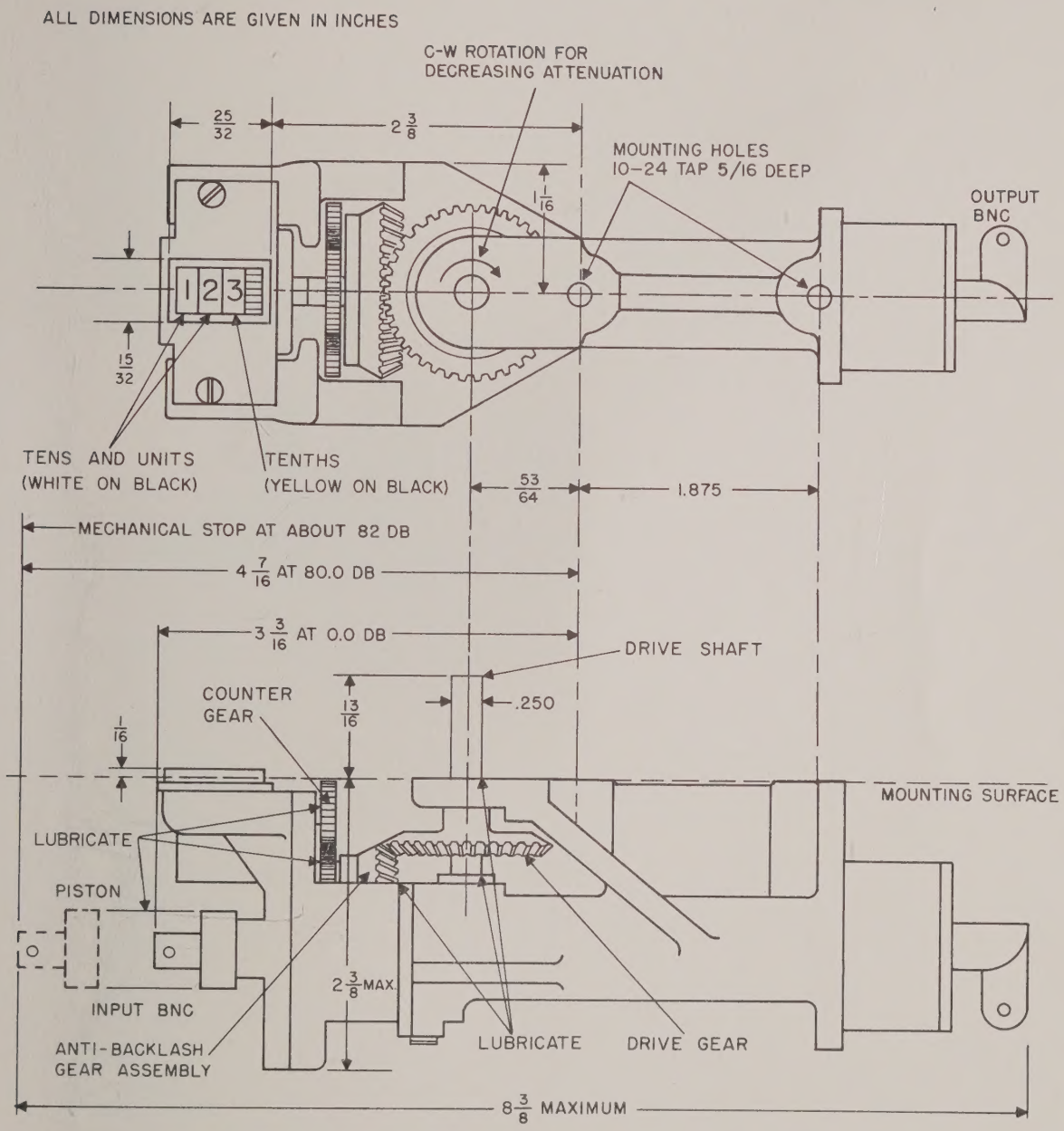

FIGURE 5. OUTLINE AND MOUNTING DIMENSIONS FOR AIL TYPE 30 PRECISION I-F ATTENUATOR